"So what will you do if string theory is wrong?"

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Abstract

I briefly discuss the accomplishments of string theory that would survive a complete falsification of the theory as a model of nature and argue the possibility that such a survival may necessarily mean that string theory would become its own discipline, independently of both physics and mathematics.

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String theory occupies a special niche in the history of science. It is the only theory of physics with no experimental backing that has managed to not only survive, but also become "the only game in town" (to quote Sheldon Glashow [1]). In addition, the theory has gained much popularity with the general public, spurred on by accessible online accounts and popular TV programs. Judging by amateur web sites and personal discussions, there seems to be a rising belief that it is a correct theory of nature.

Of course, no one knows that for sure yet. This confusion has extended even to the string physicists themselves. Although when pressed they will tell you that string theory is still in the hypothesis stage, many do act and talk as if it were confirmed that it is a correct theory of the universe. This attitude has triggered much criticism. One of the most vocal string theory critics is Lee Smolin, although he has passed through a string theory phase. In his book [2] Smolin points out that this "faith" in the string hypothesis has affected funding and hiring policies in a negative way, effectively boosting the theory's prominence disproportionately compared to other approaches to quantum gravity [3]. Another notable string theory critic is Peter Woit whose views can be found in his book [4], articles [5, 6], and web site [7]. Although there are many counterarguments to be made, it seems that string theory does receive more hype than it deserves if evaluated solely on its applicability to nature and connection to experiment.

In fact, string theory has so far failed to conform to the definition of a scientific theory. In his classic work [8] Karl Popper gives several criteria that a scientific theory must satisfy. These may be summarized as "the criterion of the scientific status of a theory is its falsifiability, or refutability, or testability". A discussion may be found in his cited original work as well as online sources such as [9]. So far string theory has failed to meet Popper's criterion. It might be argued that this situation is temporary. Eventually technology will catch up with string theory and allow us to test its assumptions directly or someone will find a way to test the theory using current technology. This hope is what keeps string theory on the list of scientific theories, saving it from the fate of astrology and creationism. The failure to satisfy Popper's definition is however a serious drawback that string theory critics will, justly, continue to point out.

So why do people continue to work on string theory? There are several reasons. We often hear that the theory is aesthetically attractive and that it would be a shame if nature had not picked such an elegant structure to use as the basis of the universe. Furthermore, it is the only model that aspires to not just be a theory of quantum gravity, but also a theory of everything;

unifying, in principle, all of known physics. The hope is that eventually we will have a complete nonperturbative quantum theory which leads to the standard model plus general relativity in the low energy, dimensionally reduced limit. Not only that, we would like this reduction to happen in a unique way. However, the possible ways we can dimensionally reduce the ten-dimensional string theory to four spacetime dimensions allows for many possible outcomes, so large that they are collectively known as the "string theory landscape" [10, 11]. The often quoted estimate of the number of these product theories is 10^{500}! If the physics we observe is just one of 10^{500} possibilities, what of the remaining $(10^{500} - 1)$ wrong ones? Why are they there? To date this is an open question. An added complication is that the well-studied portions of the landscape are far from being perfectly connected to each other.

The current situation of the theory may be likened to that of a large beautiful Persian rug that is being woven thread by thread. Usually we would start at some point in the rug and work our way systematically through the elaborate designs such that at any given time, we can see the completed portion of the rug all at once. Unfortunately for the case of string theory, the unfinished parts are not all in one place; they are scattered all over the rug. It requires a considerable strain on the imagination to visualize what the finished rug might eventually look like, or if the completed pieces will ever smoothly and continuously meet.

People like myself who are interested in some small segment of the string theory landscape that might not relate to the universe naturally are asked: "Why do you work on this theory? Shouldn't you, as a physicist, be interested in what describes nature? Why waste your time on something that you know *a priori* to be wrong?" Another closely related question is "What if someone proves that subatomic particles cannot possibly be made of strings? In that case not only is the particular theory you are working on wrong, the whole edifice has collapsed! What will you do then? Will you drop your research and switch to something else? Or will you stubbornly continue to work on the (now incorrect) string hypothesis? What will happen to all of your careers? And why take the risk in the first place?" These questions are reasonable and may be rephrased as "Are there any accomplishments of string theory that would survive such a total collapse?" It turns out that there are.

The lack of experimental results to guide us through the vast string landscape leaves string theorists with no choice but to systematically explore all of it! These explorations, even within theories that we already know are not related to nature, have resulted in the discovery of deep and

elegant mathematics. Mathematicians today work in parallel with string theorists to explore the frontiers that the latter have opened. Aside from advancing abstract mathematics, the discovery of the ADS/CFT conjecture [12] provides hope that results within a (nonphysical) perturbative string theory may be transformed to a mathematically dual (but physical) nonperturbative theory, such as QCD. If true, this duality would be a major breakthrough, and might by itself guarantee the survival of string theory in some form, even if falsified by experiment.

Studying the large number of theories in the landscape and how they are related to each other has provided deep insights into how a physical theory generally works. The string theory landscape may be likened to a vast range of samples collected and studied in detail for the purpose of understanding why theories of physics behave the way they do and perhaps guide us into answering deep questions about such things as symmetry and its origins.

So even if someone shows that the universe cannot be based on string theory, I suspect that people will continue to work on it. It might no longer be considered physics, nor will mathematicians consider it to be pure mathematics. I can imagine that string theory in that case may become its own new discipline; that is, a mathematical science that is devoted to the study of the structure of physical theory and the development of computational tools to be used in the real world. The theory would be studied by physicists and mathematicians who might no longer consider themselves either. They will continue to derive beautiful mathematical formulas and feed them to the mathematicians next door. They also might, every once in a while, point out interesting and important properties concerning the nature of a physical theory which might guide the physicists exploring the actual theory of everything over in the next building.

Whether or not string theory describes nature, there is no doubt that we have stumbled upon an exceptionally huge and elegant structure which might be very difficult to abandon. The formation of a new science or discipline is something that happens continually. For example, most statisticians do not consider themselves mathematicians. In many academic institutions departments of mathematics now call themselves "mathematics and statistics." Some have already detached into separate departments of statistics. Perhaps the future holds a similar fate for the unphysical as well as not-so-purely-mathematical new science of string theory.

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[12] The ADS/CFT conjecture, also known as the Maldacena conjecture, is the idea that to every nongravitational quantum field theory living on the boundary of a given spacetime manifold, there exists a string theory in the bulk of the manifold such that calculations in one are mathematically dual to the other via a certain well-defined set of transformations. The conjecture has been verified for a certain narrow range of supersymmetric theories. J. Maldacena, "The large N limit of superconformal field theories and supergravity," Adv. Theor. Math. Phys. **2**, 231 (1998) [Int. J. Theor. Phys. **38**, 1113 (1999)].